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Chapter 4

An Adaptive System to Link Science, Monitoring, and Management in Practice

HARRY C. BIGGS AND KEVIN H. ROGERS

Kruger has implemented a unique version of adaptive ecosystem management (strategic adaptive management [SAM]) built on a base of recent developments in ecology and business management (Chapter 3, this volume). New paradigms in ecology stress complex adaptive systems and heterogeneity, and business management now emphasizes that organizations need to continually reinvent themselves through purposeful knowledge diffusion. Establishment of SAM was favored by an interaction between certain catalysts and an existing legacy in Kruger. It differs from conventional adaptive management in having a stronger emphasis on the forward-looking component, attempting to swing the bulk of decisions into proactive rather than reactive mode. It has a strong goal-setting component evidenced by a well-developed objectives hierarchy (Keeney 1992) and strongly articulated monitoring endpoints (called thresholds of potential concern [TPCs]). The objectives hierarchy and endpoints act as a nexus for connecting science, monitoring, and management in an innovative and motivating way. This chapter describes the new management system and the challenges it presents.

Our purpose is to demonstrate how Kruger has addressed a pervasive deficit in conservation: the effective integration of science and management in and around conserved areas (Chapter 3, this volume). Ideally, the science elements (stored knowledge and ongoing research), the monitoring elements (regular state-of-the-system measurements, often classed together with the science elements), and the management elements (direct action modifying or maintaining the system) will operate as a smoothly integrated three-part unit serving common objectives.

Background

Since the 1950s, scientists and managers have collaborated under various management circumstances in Kruger, with a steadily increasing knowledge base. When the legacy that arose is viewed with current understanding, we can see that Kruger has behaved as an adaptive institution (*sensu* Holling 2001). It went through decades of the conservative buildup of connectedness and potential, entering the release phase in the adaptive cycle in the early 1990s, thus opening up a range of alternative possible management trajectories. The reorganization phase of the evolving intersection between science and management is the central theme of this chapter. The background that gave rise to this new interface was crucial to its establishment (Box 4.1).

Core Elements of the New Kruger Management System

Biodiversity management initiatives, from grassroots (Salafsky et al. 2001, or http://www.fosonline.org) to theoretical (Chapter 3, this volume), stress a small set of generic needs for success: recognition that we are dealing with spatially and temporally complex adaptive systems, clear purpose and goals, participative learning by all stakeholders and not just by their advisors, monitoring to test assumptions, and adaptive organizational processes that promote institutional curiosity and the ability to capitalize on experience, new knowledge, and surprises. The new management system of Kruger embraces each of these needs through four core elements:

- A new vision statement, heavily influenced by repeated public participation, explicitly embraces spatiotemporal heterogeneity. It is based on the three pillars of biodiversity (composition, structure, and function) and the recognition that national parks should embrace the wilderness concept and provide benefits to the populace. The statement reads, "To maintain biodiversity in all its natural facets and fluxes and to provide human benefits in keeping with the mission of the South African National Parks in a manner which detracts as little as possible from the wilderness qualities of the Kruger National Park" (Braack 1997a).
- A hierarchy of objectives (Keeney 1992; Chapter 3, this volume), an inverted tree of goals, branching downward from value-laden vision statement with increasing explicitness to technically stated ecosystem and institutional goals. The objectives hierarchy fills in the middle ground between high-level vision statements and the explicit lower-level (what exactly, by whom, and when) statements needed to realize the vision. The full Kruger objectives hierarchy and a description of techniques used to derive it are available in Braack (1997a). Figure 4.1 illustrates a small section of the objectives hierarchy relating to the influence of the atmospheric system on biodiversity conservation, of cardinal importance in the decades ahead. Table 4.1 depicts an overall outline of themes covered by the objectives hierarchy.

BOX 4.1

A Favorable Legacy and the Right Catalysts at the Right Time

How did the Kruger National Park come to develop the SAM processes it now uses? For half a century, scientists and managers worked together in Kruger building a solid foundation of interaction:

- Since the 1950s Kruger has employed its own scientists, who could interact with external scientists and assimilate their findings into the broader Kruger experience.
- Managers and scientists have long been exposed to each others' products and demands (Chapter 1, this volume). They have benefited from regular joint decision making, mutual respect for each other's disciplines, sufficient capacity and resources, and sufficient time to learn jointly from the experience that resulted.
- There is a close-knit organizational culture and much similarity between individuals in beliefs and background.

In short, a community of practice with elements of the key processes of diffusion, communication, and adoption has existed for many years in Kruger, effecting coordination between scientists and managers. Although they do not always conform to modern expectations (e.g., pseudo-fact [Chapter 3, this volume] may have dominated certain decisions), numerous examples of science-management links exist:

- Decisions on elephant culling (1967–1994) were based on research in Kruger that suggested that numbers above one elephant per square mile might permanently jeopardize vegetation recovery (Whyte et al. 1999). Careful annual monitoring of elephant numbers guided culling quotas, which thus provided putative vegetation protection.
- Mammals were exported to establish viable populations in other parks. Offtake limits in Kruger, immobilization and sedation, and likelihood of survival under conditions of transport, arrival, and release (Novellie and Knight 1994) were all based on research.
- Lions were culled in the 1970s in an attempt to reduce pressure on wildebeest and zebra populations after research demonstrated that traditional migration routes had been cut off by the western boundary fence and population modeling predicted predation impacts (Joubert 1986).
- Similarly, the culling of species such as buffalo and the evolution of water provisioning and fire policies were guided by experienced scientists and managers, based on the best information available at the time.

The science-management interaction in Kruger evolved over 40 years to form a strong partnership, but by the 1980s Kruger was seen as becoming increasingly isolated and insular. The sociopolitical changes of the early 1990s challenged the homophily of culture, belief, and background in Kruger, exposing the park as part of a bigger dynamic. The new open environment catalyzed change, and the conservative partnership provided a firm base from which to capitalize on recent innovations in resource management (Chapter 3, this volume):

- The viewpoint of nature as in balance, linear, predictable, and controllable was challenged by one of flux and socioeconomic complexity (Chapter 3, this volume).
- The history of knowledge compartmentalization (Chapter 22, this volume) and the limited use of integrating tools such as models became a constraint to advancing scientific understanding. However, interdisciplinary integration characterizing local river initiatives influenced scientific activity in general.
- The insular and autocratic decision-making organization could no longer function unchanged under the new sociopolitical system. Significant changes in administration and external partnerships necessitated that choices be justified in terms of explored options, forcing reconsideration of entrenched policies.
- Fundamentals of many Kruger science-management activities, such as monitoring, came under the scrutiny of modern science and management practices (Chapter 3, this volume), prompting a reorientation toward biodiversity and heterogeneity. This important theme is continued through this chapter.

Kruger's ability to meet these substantive challenges was significantly aided by the existence and success of the Kruger National Park Rivers Research Program (RRP; Chapter 9, this volume). Until this time external researchers had operated independently within Kruger, each collaborating with perhaps one Kruger scientist in one field. The RRP organized a strong group of researchers into a cohesive program that enjoyed autonomy from but a great deal of interaction with Kruger scientists. The RRP offered a useful model for concept development and a broader application of adaptive management for Kruger.

Initially, diffusion of RRP innovations into the broader Kruger science and management community was limited because most management and almost all research historically had been focused on the terrestrial system. The catalyst for the full-scale revision of Kruger's objectives and management approach was the call for elephant conservation and management reforms in the mid-1990s (Whyte et al. 1999). With the globalization of South Africa came international pressure to justify the need for culling, and there was a growing recognition that elephant had to be understood and managed as part of a dynamic ecosystem. The imperative of elephant management and intellectual advances brought to the table by the RRP merged to catalyze a new management philosophy, a new vision, an objectives hierarchy, and explicit management targets (Rogers and Bestbier 1997; Rogers and Biggs 1999; Braack 1997a, 1997b).

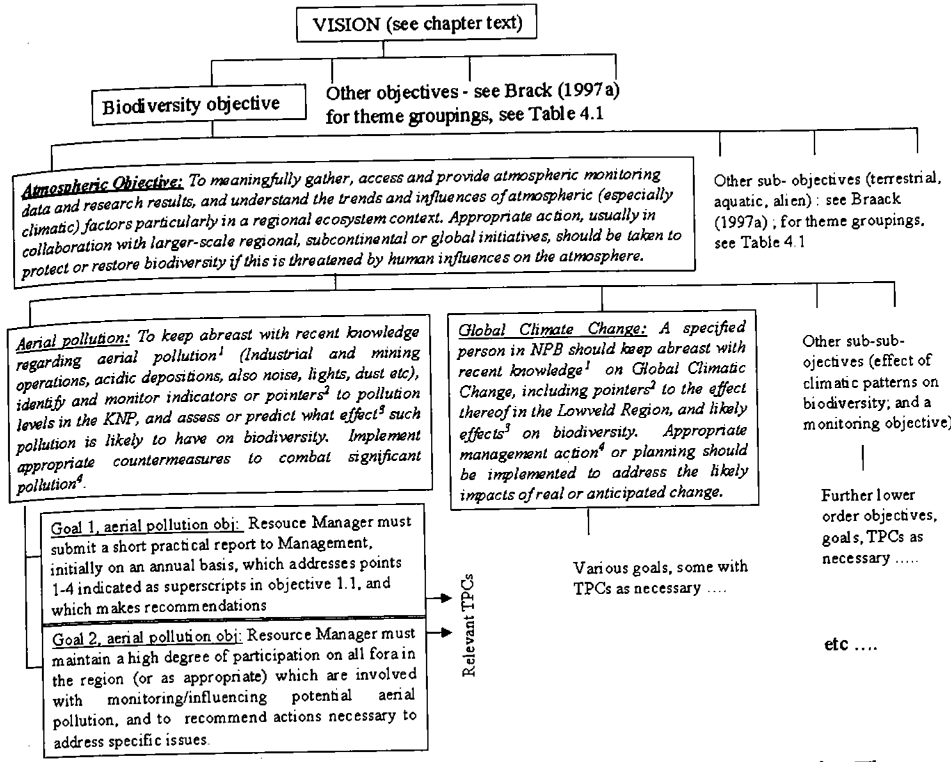

FIGURE 4.1. An example of a small portion of the Kruger objectives hierarchy. The section chosen shows the layers from the conceptual (top), just below the vision statement, to the detail (bottom). The top sections are value laden and involve public participation; the bottom sections are technical and constructed by managers and scientists.

- The concept of TPCs, a set of operational goals that together define the spatiotemporal heterogeneity conditions for which the Kruger ecosystem is managed. TPCs are defined as upper and lower levels along a continuum of change in selected environmental indicators. When this level is reached, or when modeling predicts it will be reached, it prompts an assessment of the causes of the extent of change. The assessment provides the basis for deciding whether management action is needed to moderate the change or to recalibrate the TPC. TPCs form the basis of an inductive approach to adaptive management because they are invariably hypotheses of limits of acceptable change in ecosystem structure, function, and composition. Therefore, their validity and appropriateness are always open to challenge, and they must be adaptively modified as understanding and experience of the

TABLE 4.1

An outline of topics covered by the objectives hierarchy of Kruger and the associated main monitoring (and hence threshold of potential concern [TPC]) themes. The actual objectives of the atmospheric component are shown in Figure 4.1 as an example of how each topic was broken down hierarchically.

MAIN GROUPS OF BIODIVERSITY MANAGEMENT OBJECTIVES IN KRUGER MANAGEMENT PLAN	MAIN THEME AREAS IN MONITORING PROGRAM
Atmospheric: global climate change, pollution, climate recording and networking Aquatic: pans, rivers (public relations, legal, biodiversity, integrated catchment management, relationship with upland), surface water distribution (water provisioning policy over the landscape and its effects) Terrestrial research: fire, predation, herbivory, disease, nutrient cycling, pollination Terrestrial management: fire, erosion, disease, fencing, land acquisition and consolidation, illegal exploitation, plant and animal population management, pollination Terrestrial monitoring: monitoring program, TPCs Alien impact: strategy, prevention, eradication, prohibition, research, awareness **Other major objectives of Kruger:** Human benefits: neighbor relations, staff, tourism and hospitality, problem biota Wilderness: awareness, zonation, policy and law, auditing, networking Integrated environmental management (the balancing objective): agreeing on a desired state, levels and mechanisms of trade-offs between objectives, and integrated environmental management and EIAs	Woody vegetation, including aerial photos* Herbaceous vegetation* Rare biota* Large mammal responders (aerial census)* Invertebrates Spatial patchiness Alien biota (mainly invasive plants)* Birds, fish, amphibians, reptiles, and small mammals Pollination Disease Climate (tourism staff also assist with monitoring) Fire* Erosion Landscape water Nutrient cycling River water quality and flow* Wilderness qualities

The management plan is subject to interim updating, audits, and major revision every 5 years. Each theme has TPCs, although most climate measurements are not thus linked.
*All programs in which rangers have more than just incidental involvement in at least one major component of the actual monitoring in that program.

system being managed increase (Rogers and Bestbier 1997). An illustrative set of TPCs is presented in Table 4.2.

The joint suite of TPCs represents an overall and multidimensional envelope within which flux or variation of the ecosystem is acceptable to both scientists and managers operating under the vision statement. The wider the TPCs are set, the bigger the envelope of possible system behaviors and patterns. Widely set TPCs imply that managers choose a risk-tolerant approach that avoids blatantly unsatisfactory trajectories but

TABLE 4.2

Three illustrative thresholds of potential concern (TPC) descriptions, given in sufficient detail to understand the background, definitions, scale descriptors, and rationale.

BIOPHYSICAL THEME, EXAMPLE OF TPC, AND BACKGROUND	SIMPLIFIED PARTIAL WORDING OF TPC	TIME AND SPACE SCALES FOR COLLECTION AND EVALUATION	RATIONALE AND COMMENT
Spatial heterogeneity of woody vegetation, measured as the percentage of woody cover Background: For biodiversity management, Kruger, a long, narrow park, has recently been zoned divided into four major blocks: two contiguous blocks in the center currently designated for high elephant impact (source) and two peripheral blocks at either end designated for low impacts (sink). These may swap later.	Inside any one of the four elephant management zones making up Kruger, woody cover should not drop below 80% of its highest-ever value; the mean drop parkwide should not exceed 30%.	Digital airborne remote sensing at 0.5-m resolution every 3 years, analyzed every 3 years using standardized algorithms, with calibrated corrections for scale and resolution changes in historical photography used for benchmarks.	It is believed desirable to eventually subject all large areas of the park to varying elephant impacts to ensure spatiotemporal flux in disturbance pressure. This may allow change between grass and woodland states as, for instance, recorded in East Africa (Dublin 1995)
Fire pattern, measured as long-term fire frequency Background: Assumption is that fire pattern parameters such as frequency, seasonality, intensity, annual extent, and size distribution are surrogates of biodiversity (van Wilgen et al. 1998).	Cumulative probability curve (proportion of area burnt vs. years since last fire) should not exceed stated limits specified at three points on an empirical Kruger curve typical of savanna systems: median (3.5–7.5 years), 80th percentile (5–10 years), and maximum postfire age (33 years)	Ongoing records of area burnt, at satellite image resolutions of 30m, 250m, and 1.1km, calculated annually at end of fire season and currently computed over past 30 years for coarse resolutions. Because the 30-year window moves on one year at a time, change develops slowly in this TPC.	Concern is that fires do not develop variable long-term frequency patterns. Because historical Kruger interfire period is deemed too frequent, the median TPC is acceptable only if greater than historical median of 3.5 years (lower limit).

(continued)

TABLE 4.2 *(continued)*

BIOPHYSICAL THEME, EXAMPLE OF TPC, AND BACKGROUND	SIMPLIFIED PARTIAL WORDING OF TPC	TIME AND SPACE SCALES FOR COLLECTION AND EVALUATION	RATIONALE AND COMMENT
Fish, measured as integrity of assemblage Background: This example is included as one of an index not derived specifically for Kruger's monitoring program but widely used in the broader region, in this case for river health assessments. Several such indices are incorporated in the Kruger program, also in the interest of meaningful regional results.	Fish assemblage integrity index (FAII), which takes into account intolerance index, expected frequency of occurrence, and health index per homogeneous stretch, drops below Class B (Kleynhans 1999).	Fish sampled by standardized techniques in slow, fast, shallow, and deep water and various habitat cover combinations every 2 years at six sites per Kruger stretch of river. Formula applied with expert judgment.	The assemblage should not deviate from the assemblage that would be expected in unmodified conditions (Class A) or at least in largely natural conditions with few modifications (Class B).

tolerates broadly varying conditions and patterns. On the other hand, a narrow set of TPCs implies a risk-adverse strategy that seeks to optimize for a narrow zone of variability and system behavior. Since the new vision statement was implemented, Kruger has opted for risk tolerance, believing this to allow development of greater resilience (Holling 2001).

- An adaptive decision-making process (Figures 4.2 and 4.3). The vision, objectives, and TPCs must be seen in their natural setting, the adaptive management cycle. There are many models of adaptive management (Chapter 3, this volume), all showing generically similar steps from participative visioning, through goal setting to multioption planning. The consequences of the options are thought through and tested for acceptability, and the best choice is then made and operationalized. Implementation is always accompanied by monitoring and by an evaluation and a conscious reflection step to feed back into another loop of this iterative process (Figure 4.2). We would like to stress the influence of the visioning and objective-setting step; in Kruger this affects generation of understanding (via research) and the identification of agents of change (Figure 4.3). The latter then spawns the TPCs and hence the monitoring program that audits their achievement.

Two indispensable steps govern the style and scope of feedback in the adaptive decision-making loop. The first is to determine whether the objectives and vision are being met once interventions are carried out (Figure 4.3, unpacked

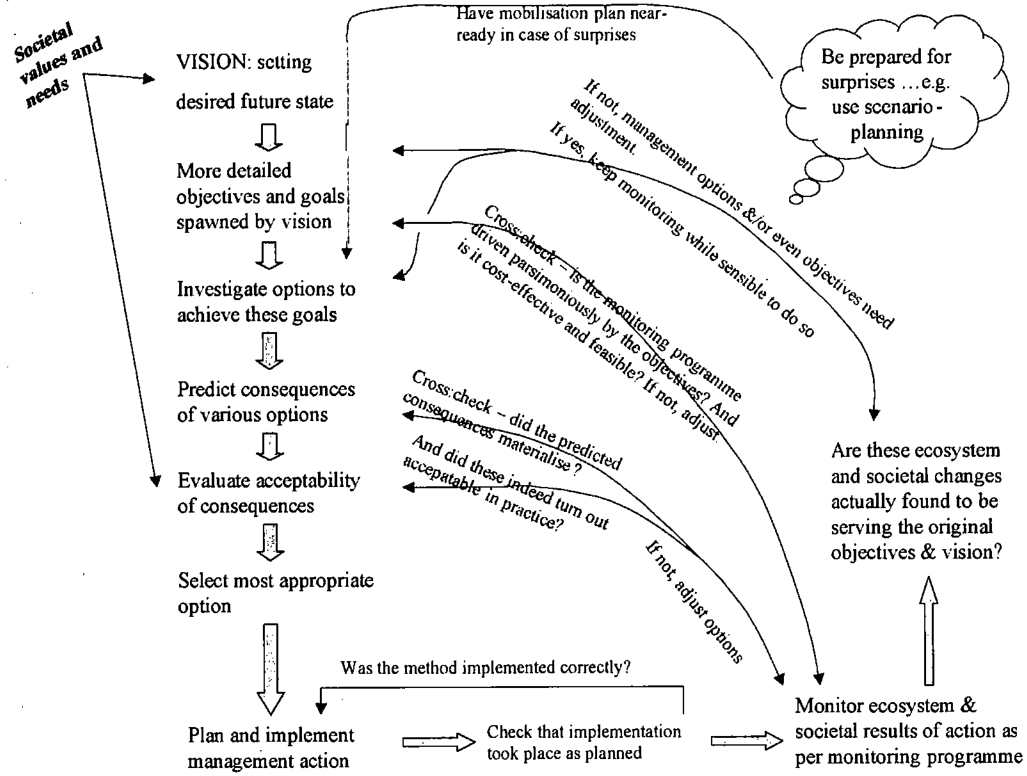

FIGURE 4.2. Generalized version of an adaptive management system, emphasizing feedbacks between objectives, actions, and monitoring.

in more detail in Figure 4.2). The second is that in Kruger, the very specific TPC step (Figure 4.3) dictates whether, when, and how management action will take place and elegantly ensures that subsequent steps check that the outcomes of management actions meet the objectives and vision.

The scope of audit thus includes ensuring that the physical implementation took place properly, that the system returned to within the TPC and that the consequences or side effects of the management actions were acceptable, that the monitoring system to achieve this is feasible and efficient, and, most important, that the objective was indeed served by the TPC returning to within limits. This comprehensive cross-checking system, if documented in the excellent tradition of Kruger's earlier managers (Chapter 1, this volume), should ensure that future managers are not left wondering why their predecessors made certain choices.

Knowledge sharing is crucial in adaptive management; we therefore stress the importance of role overlap (Figure 4.3) between scientists, managers, and other stakeholders. The central elements of knowledge sharing are discussed in more detail in Box 4.2.

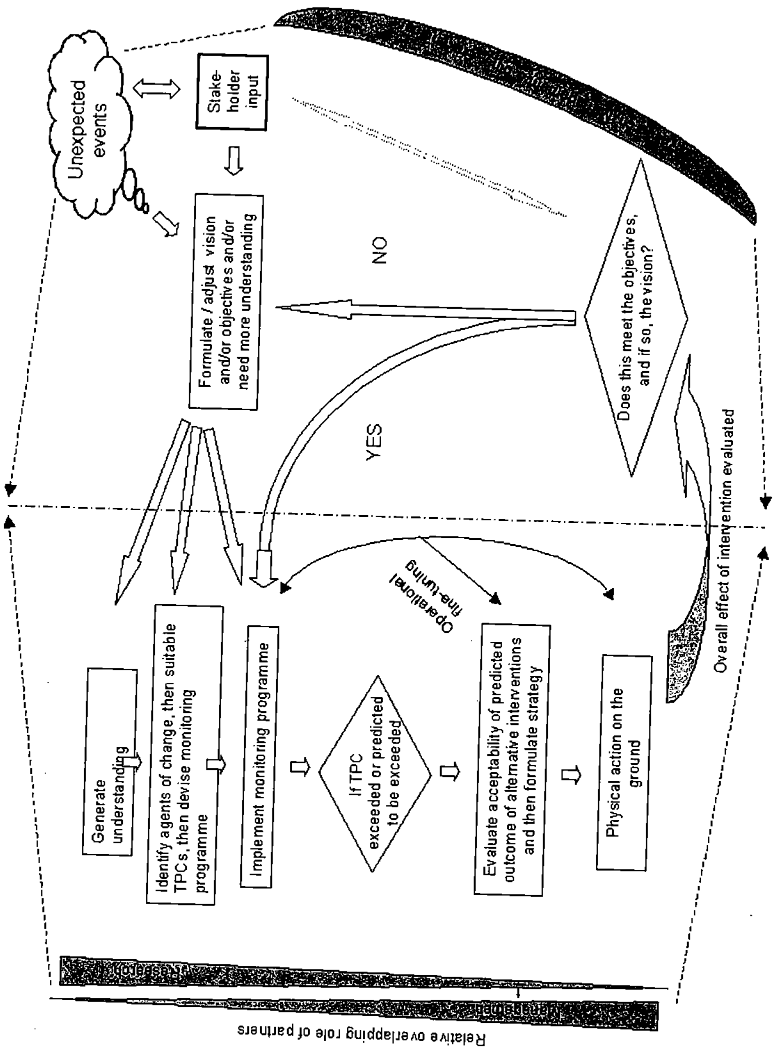

FIGURE 4.3. Strategic adaptive management processes aimed at illustrating the linkage of research, monitoring, and management processes via the use of TPCs in Kruger. These processes reflect how science and management interact with *environmental changes and societal values.*

BOX 4.2

Self-Evolving and Informal Communities as the Basis for the Transfer, Adoption, and Diffusion of Knowledge

DIRK ROUX

Sharing of perspectives and knowledge, adoption of new knowledge, and subsequent diffusion take place largely within informal and self-organizing communities. These communities of practice (COPs) provide structure for networking across organizational and disciplinary boundaries and provide connectivity between research (knowledge supply) and management (knowledge demand) fraternities. COPs serve two main purposes: to deemphasize organizational boundaries and to amplify individual knowledge at the group, organizational, and institutional levels. These communities are defined in terms of interest rather than geographic location.

Identification with and participation in a community is essential for developing good relationships between individuals and groups within a specific social system. Important relationship issues include degree of trust, ease of working together, capacity for joint problem solving, ability to resolve conflicts, openness and quality of communication, and capacity for considering what is best for the community. Through community interaction, researcher, manager, and stakeholder perspectives can coevolve in a process of mutually dependent learning.

There are three key knowledge processes within this community of practice: transfer, adoption, and diffusion.

Transfer

Knowledge transfer is essentially a communication process whereby personal experiences and tacit knowledge are shared based on common or overlapping interest. Even when knowledge predominantly moves in one direction, usually from researcher to end user, the two or more parties must participate in a series of communication exchanges as they seek to establish a mutual understanding about the meaning of the knowledge. If feasible, clear articulation of demand from the client side is very helpful. Early and ongoing interaction between researchers and managers of natural resources is the safest way to increase the degree of compatibility between knowledge innovations and the needs of resource management (ideally, the innovator should help to shape these needs). Scientists become aware of implementation realities, such as capability and resource constraints, at an early stage. Managers get to experience the new knowledge and technology in action during pilot applications and have time to develop ownership. The overall result is that a natural progression is fostered among all parties, from research to design to adoption and subsequent implementation.

Adoption

Scientists often mistake the handing over of a final research report for the transfer of knowledge or technology. Resource managers are left with a product in which they have little ownership that may not be suitable to their particular set of resource realities. True transfer ends with adoption, which implies both emotional and financial commitment to sustained or routine use. Once opinion leaders have adopted new knowledge, it is transferred to community and organizational levels where formal resource allocation takes place. This knowledge can be diffused and deployed so that, through practical application, its latent value can be realized.

Diffusion

Diffusion, as defined by Everet Rogers (1995), includes spontaneous or unplanned spreading of new ideas and innovations as well as planned, directed, or managed spreading (also called dissemination) of new ideas and innovations. The rate at which diffusion takes place determines to a large degree the rate at which individuals and organizations can expand and renew their knowledge and technological capabilities. When new knowledge is created, adopted, and diffused, social change occurs. Therefore, diffusion has a direct influence on the ability of people and organizations to respond to change. Two key necessary conditions for successful diffusion in resource management agencies are critical levels of people's capacity to absorb new knowledge and critical levels of organizational capability (combination of knowledgeable people, equipment, strategies, and logistical infrastructure) to deploy and apply new knowledge.

Derivation and Influence of the Objectives Hierarchy

The first step in deriving the Kruger objectives hierarchy was to identify the potential key elements (biodiversity, human benefits, wilderness, naturalness, and custodianship) of a vision statement, representing societal needs and values for Kruger. These were then debated at public meetings, and suggested changes were incorporated for the next iteration of public meetings. This publicly accepted vision was broken down at a series of (mainly internal) meetings into a hierarchical series of objectives of increasing focus, rigor, and achievability. This process was also guided (Rogers and Bestbier 1997) by context (international, national, and local realities, such as obligations under biodiversity agreements) and by a set of operating principles (such as least interference in the ecosystem to achieve a particular aim and use of the precautionary principle). Upon completion of the hierarchy, management (Braack 1997b) and monitoring policies were derived, which were compliant with these objectives.

The finest level of the hierarchy represents achievable and testable operational targets. The concept of these targets eventually crystallized as TPCs at a groundbreaking meeting of 30 South African scientists helping South African National Parks (SANParks) to derive a monitoring program to support the new objectives. The recommendations of the meeting determined the current spread of monitoring themes summarized in Table 4.1. The emphasis on heterogeneity in the objectives necessitated a broadening of the scope of the monitoring program to assess the consequences of agents of change for biodiversity management. To cement public acceptance, several of the new management policies, including the contentious proposal for elephant management, were taken back to public forums, at which the policy was traced back to the original vision.

The new objectives hierarchy resulted in several new or revised policies:

- A revised elephant management plan, with high- and low-impact zones in an ecosystem-level adaptive management experiment (Whyte et al. 1999)
- A plan for a new 20-year landscape-level fire management trial (Braack 1997b) designed to elucidate the effects of a range of fire management systems and overcome limitations of previous fine-scale experiments
- A revised water-provisioning policy (Braack 1997b) stressing surface water as a determinant of landscape heterogeneity (Chapter 8, this volume)
- A new recreational opportunity zonation plan with varying grades of wilderness purity (Braack 1997b), expanding opportunities in a heterogeneous land-use framework
- New liaison rules to elicit benefits for and greater participation by neighbors (Braack 1997b) who had been previously marginalized

Not all of these changes originated during this revision; indeed, several were evolving at the time. The new management plan with its explicit objectives gave each issue a firmer framework. Most were directly influenced by the heterogeneity paradigm (Chapter 3, this volume), a cornerstone principle in the review. The commitment of the park to reconsider the plan every 5 years builds in longer-range adaptive possibilities to the policy management life cycle. One internal midterm audit on achievement in terms of objectives has already been conducted.

Staff restructuring and reallocation took place in research and management components to better address objectives. Research regrouped into system ecology, species and communities, and human impact programs (see Figure 22.3, this volume), and a river manager was appointed for the first time. The new broad scope of the objectives hierarchy exposed many new research needs by an initiative that audited the existing and historical range of research products against information needs defined by the objectives. These were publicized

(Freitag and Biggs 1998) as opportunities for research collaboration and drew in a new range of participant scientists and research approaches.

TPCs as Mediators of the Science-Monitoring-Management Relationship

By its nature, monitoring should provide a common working ground for research and management. The use of TPCs mandates and further integrates participation of both research and management. Although monitoring in Kruger is a joint function of Scientific Services and Management components, we suggest that the Kruger experience with TPCs can also contribute to other settings, such as in agencies with separate monitoring sections. We discuss the role of TPCs in Kruger by following the sequence of steps outlined in Figure 4.3.

Under the vision and objectives of the Kruger, the Research Section is seen as being responsible for generating the understanding needed to set and test the TPCs. For research, this process represents the development of hypotheses (relevant to the objectives) in varying levels of confirmation. Indeed, research not substantively linked to this aim has come to be regarded as less necessary. On the other hand, much fundamental research ceased to appear remote to park needs, linking to management and conservation (via the objectives hierarchy and the TPCs derived under it) and giving it new justification. Useful TPCs have become sought-after deliverables in the organization, and research is judged according to the ability to deliver them. Research deemed at first sight unconnected to TPCs is considered important if it generates a better basis for the interpretation of existing TPCs or the development of new and ecologically more appropriate TPCs.

The Monitoring Initiative's task under the vision is to measure and assess the state of the Kruger ecosystem in a focused way. Since the advent of TPCs, researchers and others responsible for monitoring jointly develop and evaluate the monitoring program with TPCs as the central focus. Because prior agreement has been reached on endpoints (TPCs), they are taken seriously in formal organizational decision making. This provides powerful motivation for monitoring staff, who appreciate the context and constructive outcome of their efforts. In practice, the initial calibration or setting of TPC levels at which the stakeholders agree to become concerned about ecosystem change can be difficult, yet it is essential to initiate SAM. For certain TPCs, these levels are little more than educated initial guesses, but for others can already be closely linked to levels presaging well-understood ecosystem endpoints. The only monitoring themes we consider partially exempt from TPCs belong to the "significant surprise" category. Where important unexpected events cannot be predicted, their indicators must thus be measured continuously, even without a TPC framework; this includes routine weather measurements and aspects of hydrology.

The Management Section oversees and implements the activities that will support ecosystem integrity, such as taking physical action (e.g., closure of water, erection of fences, translocation of animals) or seeing that the system is left to recover on its own. Under TPC-based operating rules, they manage by exception and therefore should act only when a TPC is exceeded or, better still, once it is predicted to be exceeded. If managers or any other group are uncomfortable about the criteria and monitoring themes that have been selected (albeit with their initial input), they are free to challenge either the use of particular TPCs or their particular levels, via the Research Section, which is responsible for maintaining the list of TPCs. Once TPCs are tabled (formally reported as having been exceeded or likely to be exceeded)—and assuming they are not immediately recalibrated—management is activated via the rest of the SAM cycle. Options are generated, consequences predicted, and acceptability evaluated. The best strategy is chosen, implemented, and continuously reevaluated against the stated objectives and goals. Management's ability to return the situation to within TPCs thus becomes a visible process in the organization. This lends transparency to the process, which prevents misunderstandings and any perception of deception. There is an explicit additional check to ensure that returning the system to within the TPC concerned actually serves the intended objectives and the vision. This continual feedback and crosschecking adjusts the system in a truly adaptive way, and the more goal-oriented and predictive the system is, the more strategic it becomes, approaching the ideals of SAM.

In this way, the suite of TPCs acts as a central hub around which research, monitoring, and management activities can be sensibly unified. This works if there is committed and full buy-in to a common vision and objectives, an agreed decision-making process (in the Kruger case, SAM) is used consistently in a business environment conducive to its success, and the TPCs are viable.

TPCs are likely to be robust, defensible, acceptable, and practical if they are biologically and ecologically meaningful, statistically definable, robust, and defensible; logical and concise, unequivocally stated in exact detail; conceptually understandable and sufficiently intuitive to be manager-friendly; and technically and financially feasible to develop, implement, monitor, and maintain. Choice of indicator has a major influence on feasibility.

When TPCs are exceeded or predicted to be exceeded, a formal submission must be made to a joint decision-making committee tasked with decisions on ongoing ecosystem management. In the Kruger case, this committee contains senior science and management staff and meets bimonthly, although provision is made for shorter-term handling of emergencies. The typical headings or topics addressed in a submission for evaluation by such a body are as follows:

- Background: discuss relevant objectives, why the TPC was originally chosen, and what it states and means; identify events that led up to exceedance or predicted exceedance and the negative implications for biodiversity conservation

- Exact statement of exceedance, usually repeating the exact wording of TPC, and measurements that show exceedance or predicted exceedance and, in the latter case, by when and with what confidence
- Additional supportive or collateral evidence to assist interpretation
- Alternative possible management responses, with pros, cons, and their anticipated results

When such a submission is tabled in this way, the joint decision-making committee can effectively evaluate the acceptability of predicted outcomes and formulate strategy, enabling specific actions to be launched (Figure 4.3). Sometimes the outcome is that more information is required before a final decision can be made, but it is extremely important to ensure that this does not become an excuse for inaction. Table 4.3 provides narrative examples of the life cycles of TPCs that have been tabled.

Outcomes of TPC Use

In more than 3 years of formalized operation, Kruger has tabled 21 different TPCs, many two or three times. The necessity of repeat notification is an issue Kruger is learning to deal with. Alien species invasions provide a good example (Chapter 19, this volume) because the mandate of a national park, ideally, is to preclude them entirely. The first-level TPC in Kruger therefore is exceeded on arrival or impending arrival. Because it is seldom possible to eradicate them once they are introduced, it is counterproductive for TPC alarm bells to ring every time a plant is sighted. The next level of alarm can be invoked on criteria relating to spread or densification (Chapter 19, this volume). In other cases, such as complex, chronic "outside" threats (a cardinal example is river sedimentation from upstream areas outside Kruger; Table 4.3), keeping the TPC on the list can motivate managers to not let the matter rest until the ecosystem is considered out of danger. Clearly, too many persistent alarms will dilute interest and effort, underlining the need to balance institutional response capacity with reality.

The breakdown of categories of these tabled TPCs is: river flow and quality, 5; alien plants, 8; alien fish, 2; *Varroa* mite (a serious alien parasite of bees), 1; alien birds, 1; rare antelope, 3; and fire, 1. Although they can be classified in slightly different ways, it is clear that management focus in Kruger has shifted since the introduction of SAM. This shift is away from traditional wildlife management topics such as water provision, population regulation, and fire management. Many other changes, such as paradigm shifts in ecological understanding and poverty relief campaigns to clear alien species (Chapter 19, this

TABLE 4.3

Four illustrative TPCs that have been tabled in Kruger, with a description of the lead-up and outcome.

EVENT OR LEAD-UP	TCP EXCEEDED OR EXPECTED TO BE EXCEEDED	DESCRIPTION AND OUTCOME
Silt release episode on Olifants River (from Phalaborwa barrage, just upstream of Kruger's western boundary)	Water quality: turbidity exceeded maximum as set for Olifants River. Resulted in fish kills.	Had happened several times in previous decade; meant to have been prevented each time thereafter; committee decided letter of complaint (as in previous years) insufficient; outcome was serial meetings with full environmental management plan developed by the company operating the barrage.
Unintended fire (cause of fire meant to be primarily lightning; fire started by transmigrants crossing park from Mozambique and by other anthropogenic causes regarded as undesirable)	Area burnt from anthropogenic causes exceeded allowable percentage in all years since 1997.	Early warning in van Wilgen et al. (1998) that cause of fire has no biological significance. Committee seemed initially unconvinced of seriousness of TPC despite having approved it originally. After several resubmissions with more detail and adjustment, recalibrated for evaluation over a composite 10-year period starting in 1992. Later seen to be clearly on trajectory to exceedance of this TPC, and original TPC deemed retrospectively to have been correct. Major policy revision followed; new policy implementation began in 2002.
Sabie River alluviation and loss of bedrock influence (as triggered by various models developed by Kruger National Park Rivers Research Programme)	Directional loss of bedrock influence over a predicted 20-year period, following monotonic change since earliest aerial photos in 1940s, with modeling support on both riparian species and geomorphic indicators (see Chapter 22, this volume).	A major seven-point strategy and longer-term integrated catchment management outline was prepared after second retabling, with good ownership of problem taken. February 2000 catastrophic floods were thought initially to have solved problem (which until then was beyond model's verifiable capability), but it soon became clear that sediment was only redistributed and that the major trend was still present.
New occurrence of alien plant *Chromolaena odorata* reported along rivers	New occurrence: alien with listed high index of potential threat. Multifocal, reported by alien plant removal.	Working for Water crews removed individuals found, but islands in rivers problematic. Surveillance sharpened. Subsequent relistings led to development of multitier TPC system, with confinement at low densities (with appropriate TPCs) now targeted.

volume) have also influenced this shift. In concert with these other changes, TPCs have been influential in making Kruger a functional adaptive management site.

The preemptive nature of Kruger's SAM system has resulted in more proactive behavior. For instance, river sedimentation patterns have been predicted to reach unacceptable levels many years hence (Chapter 9, this volume), but actions are now taking place to remedy this situation ahead of a crisis (Table 4.3). However, it is not always possible to predict the exceedance of a TPC. For example, in the past there have been frequent unexpected silt releases from a barrage operated by a mining company in the Olifants River west of Kruger's boundary, resulting in fish kills. When the most recent release was dealt with under the SAM system (Table 4.3), Kruger was able to negotiate an environmental management plan with the mining company, which is likely to provide a durable solution.

Rare antelope management issues have also benefited from SAM; in previous years, they were controversial and characterized by inaction (Grant and van der Walt 2000). The recognition that sable antelope populations had fallen below TPC limits led to rapid agreement that there was a problem. A concerted research effort resulted and is expected to provide the understanding needed to solve the problem. TPCs had thus facilitated agreement among holders of divergent opinions. Like all other TPCs, the rare antelope TPCs are contestable. What made the difference this time was the clear understanding that decisions should be made on a TPC and that this TPC could not simply be changed. The debate around actual levels of TPCs must take place outside the pressurized atmosphere of the joint decision-making meeting. When tabling of a TPC challenges vested interests, there may be a temptation to recalibrate during the meeting to simply avoid the problem.

This type of situation has happened only once in the 3 years of operation of the system. The TPC for unintended fire (Table 4.3) was changed in such a way that it would be evaluated after 10 years rather than annually. Long before this 10-year period had elapsed, managers experienced difficulties stopping unintended fires, and scientists predicted that the TPC would be exceeded regardless of management action. This led to a major fire policy revision (Chapter 7, this volume) that in retrospect could have been elicited sooner, after the first tabling of the TPC.

National and international counterparts have expressed much interest in this system; two formal independent evaluations bear mention. One study (Duff 2002) evaluates Kruger for progress in SAM; although much remains to be achieved, the design is described as promising. A recent strategic review by McKinsey and Company (2002) proposed this adaptive management approach for wider use in SANParks.

Challenges

The explicit articulation in the objectives hierarchy provides clarity for each stakeholder concerned directly or indirectly with the biodiversity and ecosystem briefs of the Kruger mission to formulate their approaches to meet these aims in a heterogeneous ecosystem. There is a common ethic of operation (SAM), and there are endpoints consistent with societal values and operating principles. There are also emerging challenges.

Knowledge Management

Maintaining and updating a bank of TPCs, especially when they are being actively used, criticized, and refined, entails the challenges of maintaining any volatile living document. Protocols allowing challenge and revision in an orderly but nonimpeding way, and the consequent updating and version control, are issues facing the Kruger Research Section.

Knowledge management (Allee 1997) is a central issue. After a TPC is tabled, the tendency is for several unpredictable threads of information flow to arise as implementation proceeds, especially in response to a novel or complex threat. These threads are documented at varying (not always appropriate) levels of quality. A protocol and environment are needed in Kruger for a continuous "roping together" so that the organization benefits appropriately from the overall experience. This is one of the more difficult aspects of knowledge management (Box 4.2). Shared learning is occurring in several ways; for instance, a core team of enthusiasts has formed a community of practice that continually reworks and improves the SAM system (Rogers et al. 2000). The ultimate aim is to achieve a SAM-TPC system that runs smoothly, with products leading to the next actions in a sustainable feedback loop.

Management Activities outside the TPC Framework

Certain classes of management activity continue to receive resources and attention without being evaluated against a TPC framework, such as bovine tuberculosis control. Here veterinary regulations and clinical-scale sentiments play a strong role. The pressure triggering such management actions thus is usually legal or sociopolitical (nontariff trade barrier laws or a scare that a certain disease may have disastrous effects) and not the result of the exceedance of any TPC. TPCs and these realities must converge: either managers should agree to be less concerned (if current TPCs are not likely to be exceeded), or appropriate but explicit sociopolitical TPCs should be developed. The latter might take place in the same way that environmental water requirements (used as Kruger

TPCs) are balanced in legislation against other water needs (Chapter 21, this volume). This would require a skilled SANParks negotiator to continuously facilitate trade-offs between veterinary control and biodiversity aims, much as the Kruger river manager does for water releases to meet biodiversity goals. This will prevent operation outside the framework of common agreement about the desired envelope of conditions for Kruger.

How Many TPCs?

Kruger was overambitious in its first attempt at SAM. The full planned suite of themes and TPCs has yet to be implemented. Even if this were feasible, some consider it undesirable because the large number would tend to limit ecosystem flux and reduce ecosystem resilience. The large initial set of TPCs is helping us to learn, and feedbacks within SAM should lead to downscaling to the most parsimonious, effective set. Scaling down may also be driven by cost. We should measure what is needed, not what the organization knows how to measure or what biologists like measuring, remembering that the wide scope of Kruger's objectives inherently leads to more rather than fewer TPCs.

How Early Is Too Early, Given the Risk of a False Alarm?

The challenge is to blow the whistle before exceedance, whenever trajectories are seen to be heading in the wrong direction. At the same time, one wants as few as possible false alarms. This is a challenge in a system where wide variation within the accepted envelope is desired. In our experience, scientists want to check the validity of their measurements rather than blow the whistle. To counter this caution, it may be advisable to encourage TPC submission even if subsequent confirmatory investigations or developments lead to withdrawal of the warning as false. In practice, no false warnings appear to have occurred in Kruger to date, although we feel that some TPCs that should been tabled have not been.

Basing management on monitoring may be necessary but not sufficient in that even the Kruger TPC system, tuned to its most sensitive possible level under the vision, may not successfully identify all threats early enough. A threat recognition and amelioration system (Margoluis and Salafsky 2001, or http://www.bsponline.org), sensibly combined with this SAM-TPC system, may prove productive.

Looking from Inside or Outside the Desired Envelope

Many management plans for conservation agencies set targets that they attempt to reach rather than defining a desirable envelope in which they want to stay, which is the strategic feature of SAM. This dichotomy may reflect the level of

existing compliance to the desired set of ecosystem conditions. In agencies regulating areas that are mostly outside the desired envelope, targets may be a more practical formulation. The Kruger comes with a history, at least if judged by perceptions, of being mainly inside the envelope, so the TPC formulation expressed in this chapter is considered appropriate.

Conclusion

This chapter has discussed SAM, a strategic (forward-looking) application of adaptive management with compatible and well-articulated goals and endpoints. The nuances of a TPC are: a worry level to monitor, a hypothesis to examine, a traceback to a particular agent of ecosystem change, an achievable environmental goal, and one dimension of the composite desired envelope represented by objectives. These have proved of value to Kruger in integrating science, monitoring, and management in a system characterized by heterogeneity. We believe the greatest leverage for SAM can now be obtained via development of ongoing shared learning skills, particularly as ecosystem management widens its stakeholder base. Future evaluations will tell to what extent we have advanced constructively.

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PA

A Templat
Savanna Heteroge

The key components of ecological heterogeneity were outli
Pickett et al. (Chapter 2) as agents, substrates, controllers, and r
ders. The chapters in Part II of this book concern the main a
substrates, and controllers of Kruger's heterogeneity, setting u
III to deal with a selected set of responders. Agents of heterog
covered here include fire, herbivory, and drainage, and sub
range in scale from the geological formations underlying the
of Kruger to nutrient pools in particular soil types and plant co
nities. The availability of surface water is an example of a contro
that the dispersion of drinking sites influences the distributio
abundance of water-dependent grazing ungulates and therefore
controlling influence on agents such as herbivory and fire. A
controller is land use in the upper catchments to the west of K
boundaries, which strongly influences the flow of water and th
osition and movement of sediment along Kruger's main river
quent visits back to Chapter 2 (especially Figures 2.2 and 2.3)
reading through Part II will help the reader understand both th
ceptual framework and the functional links between key comp
of savanna heterogeneity as they arise in each chapter. For an a
perspective, Rogers and O'Keeffe (Chapter 9) describe how h
geneity thinking was first brought into the Kruger experience th
the Rivers Research Programme, in which the conceptual fram
proved useful for integrating science and management in the s
of ecosystem conservation.

In simple terms the topics covered in this part of the book rep
the main drivers of Kruger's heterogeneity. The spatial configuratio
physicochemical properties of parent rock, interacting with a dynam
matological pattern, give rise to the functional attributes of ecosyste

The Kruger Experience

ECOLOGY AND MANAGEMENT OF SAVANNA HETEROGENEITY

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